Volume 30 January, 1944 *Number 1*

Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

Low Temperature
Grease Research

PUBLISHED BY
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TEXACO LOW-TEMP Grease

LUBRICATION

A TECHNICAL PUBLICATION DEVOTED TO THE SELECTION AND USE OF LUBRICANTS

Published by

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Low Temperature Grease Research

COLD can be natural or induced. In aviation, we are chiefly concerned with the effects of cold when high altitude flying requires bearings and gear box mechanisms to function at temperatures which may approach minus 100 degrees Fahrenheit. These mechanisms can function effectively only so long as their lubricants permit free turning. Control bearings and small gear mechanisms are of particular concern. There are some 1500 ball bearings in the assembly of a bomber or multi-engined transport plane; from 500 to 800 in the small fighters or pursuit ships. Sluggish action of any of the control bearings, wheel retractive mechanisms, or bomb-bay doors may mean fatal failure of the mission. Hence our concern in the matter of low temperature grease lubrication.

LOW TEMPERATURE BEARINGS IN THE POST-WAR ERA

The lubricants which have been developed to enable military aircraft bearings to meet low temperature requirements so dependably, still will be greatly in demand after wartime restrictions are lifted. Then industry will take its turn. Very often motors, conveyors and other food handling machinery in refrigeration service can function best when located close to the product. The pre-war problem was sluggish bearings, if temperatures much below zero were encountered. The post-war solution will be the lubricants which the Petroleum Industry has developed for aviation to insure free rolling motion at temperatures approaching −100° F. The Refrigeration Industry will not lose sight of these tools which can promote lower temperatures for cold storage, food preservation and scientific research.

It has been stated that cold is natural or induced. Fig. 1 shows how natural it can be over various parts of the United States. Obviously, however, laboratory equipment could not be carried to these heights. Accordingly cold was brought to the research laboratory by means of refrigeration. With the aid of the physicist, the research chemist and mechanical engineer, insulating materials and refrigerants were combined in the building of a cold box in which any combination of small ball bearings, gears or greases can be observed at stratosphere temperatures. Favorable lubricants later are subjected to flight testing. Those which pass give greater assurance that "failure to return" will be a less prevalent headline. This research may influence post-war developments markedly.

HOW COLD VARIES

Figure 1 indicates how the height of the stratosphere varies from around 55,000 feet over the Equator down to 30,000 feet at the North Pole. Why? Because the *stratosphere* is that layer or zone of air lying above the region of atmospheric convection. The thermal agitation of the air over the hot equatorial zones of the earth drives the stratosphere upward, whereas, it settles downward in the terrestrially cold Polar regions.

The *troposphere* is defined as the atmospheric region lying between the earth and the stratosphere, where convection or mixing is sufficient to promote a regular decrease of temperature with increase in altitude. It is obvious, therefore, that *troposphere* temperatures may be extremely low over the torrid equator as this air zone is well mixed by thermal convection currents for a great height. The *tropopause* is the dividing line between the *stratosphere* and the *troposphere.*

Because of the varying altitude level of the stratosphere, a curious fact exists concerning upper atmospheric cold; the lowest temperatures are formed over the hottest parts of the earth as indicated by the "balloon over Miami" (–120° F.) shown on the chart. Over the North African desert, a measurement of —112° F. has been reported by an official of the U. S. National Bureau of Standards in connection with flight problems.

While study of a great many measurements indicates the *average* temperature of the stratosphere to be about –67° F., there are, of course, wide variations from this figure because of the variable height and nature of this atmospheric zone. Warm pockets as well as many cold pockets exist in this striated, poorly mixed layer. The stratosphere shows a higher altitude in the summer than in the winter, and is correspondingly higher over zones of high atmospheric pressure.

RESEARCH AND DEVELOPMENT

With laboratory equipment available for testing lubricating greases at very low temperatures, the research chemist could further intensify his study of how to make these greases .Their component materials proved to be most important. Then he also had to study bearing and gear design as related to proper lubrication.

The Manufacturing Procedure

The method of manufacture of a low temperature grease involves quite naturally a specialized process. Some authorities are reported to favor the high heat method of manufacture. This method, however, is hazardous when carried out on a large scale because of the use of mineral oils of low viscosity, which are necessary for successful low temperature operation of the final grease. In addition, special equipment is required for homogenizing high-heat greases after cooling.

In view of the above, the use of conventional kettle equipment is preferred wherever practicable, doing away with the necessity of hazardous, high-heating which may jeopardize the safety of personnel and plant.

Laboratory Performance at Low Temperatures — Evaluation Methods

Concurrently with the development of suitable manufacturing technique it was also necessary to perfect a suitable apparatus for measuring the resistance a bearing would show to starting and turning when lubricated with the grease under consideration, and subjected to low temperatures comparable to the upper reaches of the atmosphere or Arctic ground conditions. The Navy single spindle torque test apparatus[1] was one of the first developments. Temperatures down to —100°F. have been obtained in this apparatus by suitable selection of refrigerants.

Later a four-spindle apparatus was devised. This piece of equipment is now built according to the plans outlined in Specification AN-G-3a for low temperature grease. It is called the Annular Bearing Engineers Committee Cold Box though it is primarily the design of the Norma-Hoffmann Bearings Corporation. By removing the spindles a small cold chamber is provided for the testing of aircraft gear box mechanisms.

Low Temperature Penetrations

Low temperature penetrations also are useful in predicting the hardness of various products at comparable low temperatures. For instance, it has been shown that one of the most unique low temperature greases on the market today (Grease A) has the consistency of approximately a No. 3 (medium softness) cup grease at —96°F., whereas under the same conditions another product (Grease B) has a hardness of approximately that of water-pump grease, or cup grease No. 6, being very stiff. A digital and visual examination of water-pump grease in comparison with medium consistency cup grease presents a striking illustration of the differences in low temperature consistency existing between these products.

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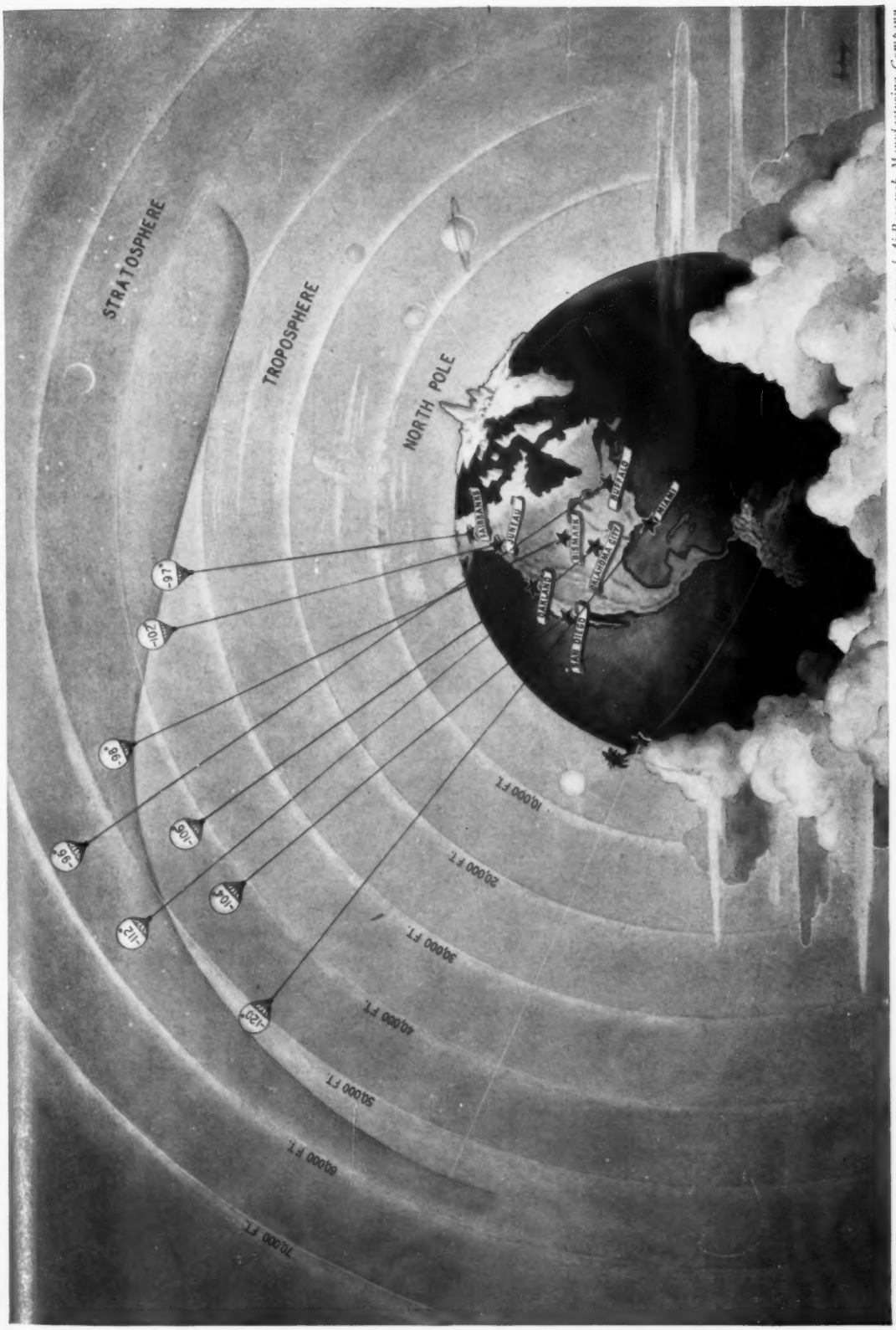
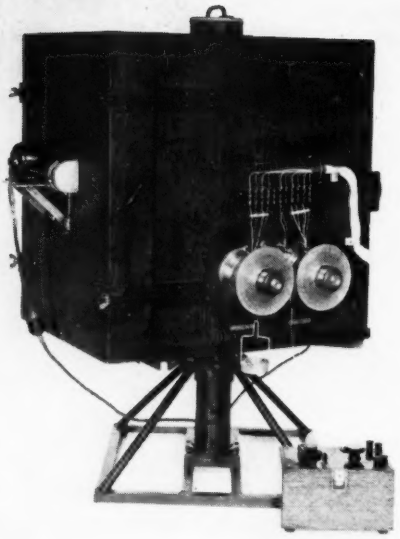
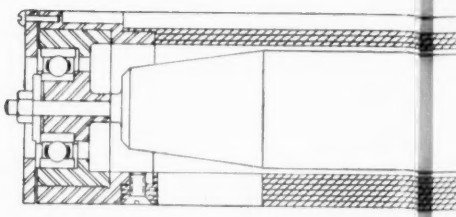
[1]Reference a paper on "Performance Specifications for Greases" by R. C. Adams and H. E. Patten, presented at the July, 1941 meeting of the American Society for Testing Materials.



Courtesy of AiResearch Manufacturing Company

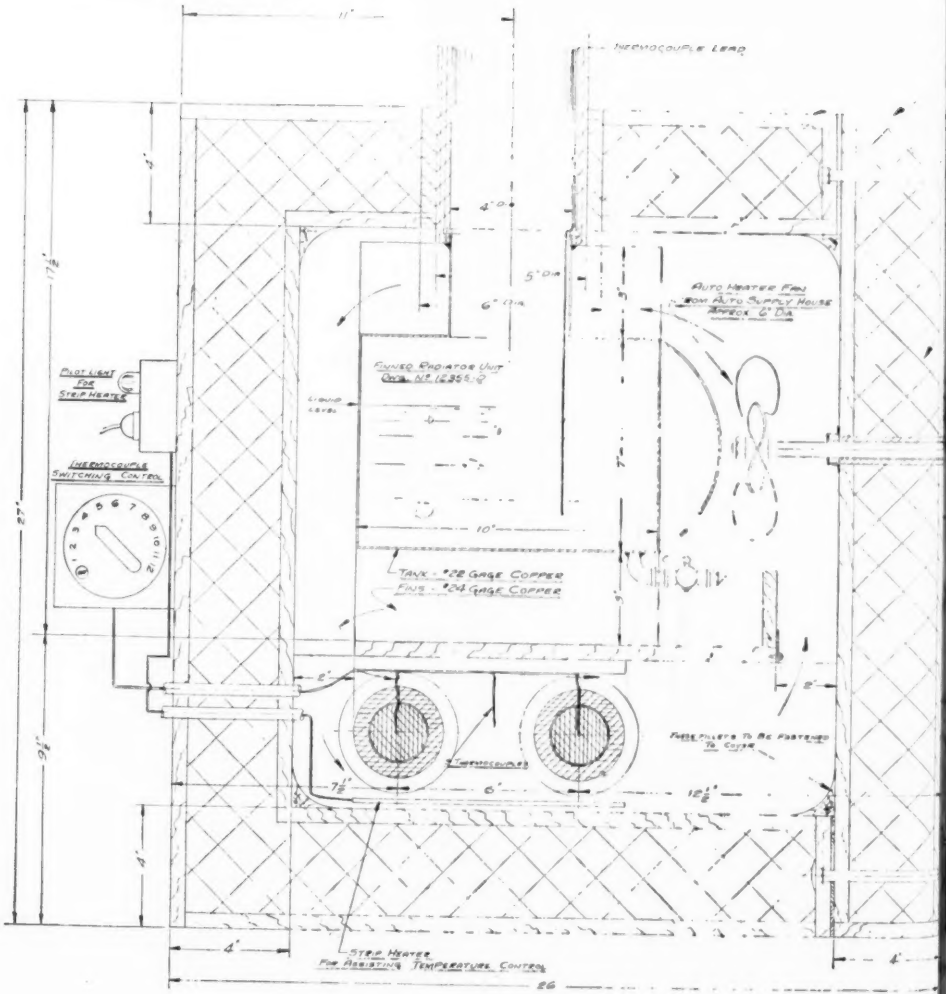
Fig. 1—Showing how the trial balloons of the U. S. Weather Service indicate temperatures at various elevations over different parts of the United States.

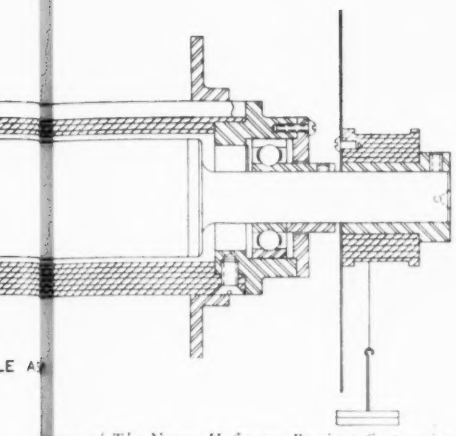




COLD TEST SPINDLE A

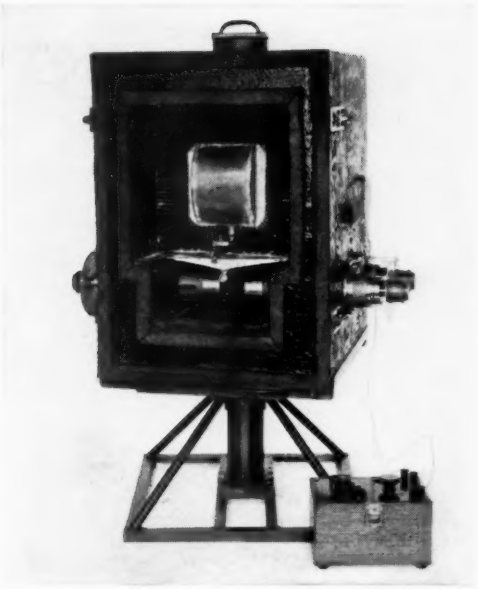
Details of the four-spindle A box, showing constructional fe

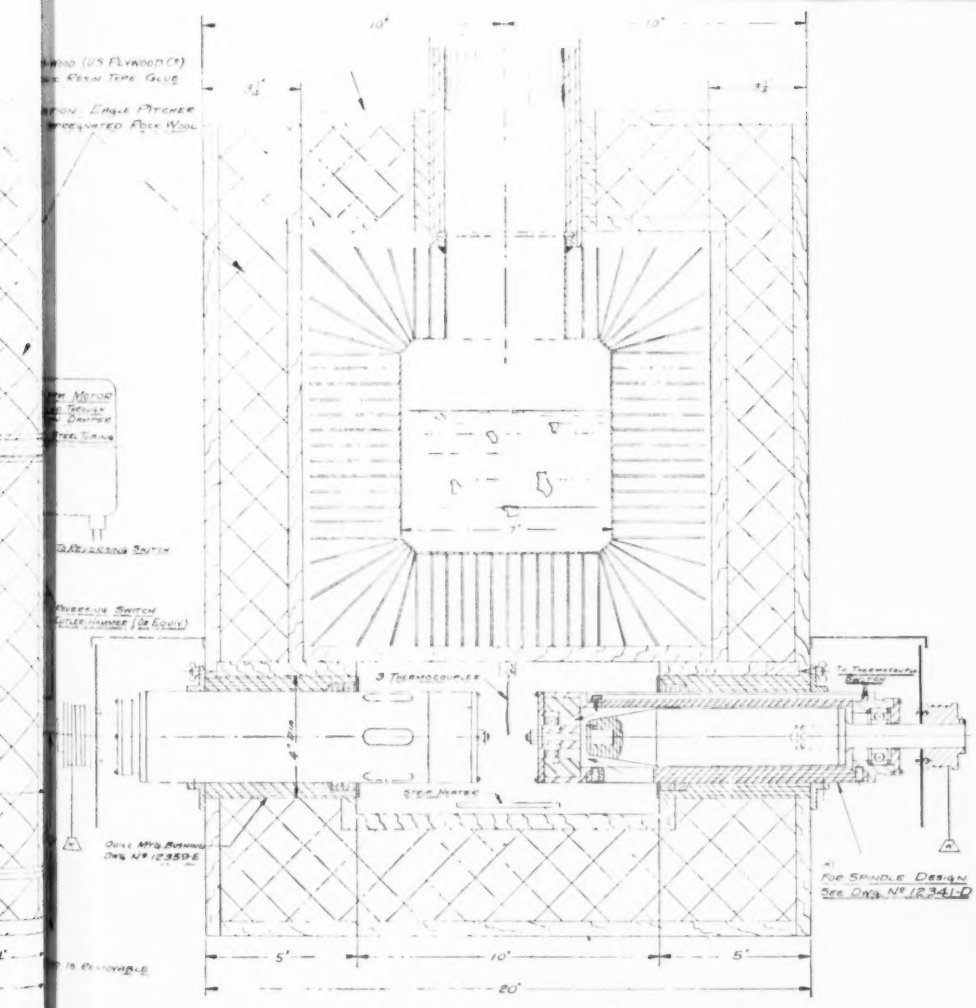




...tesy of The Norma-Hoffmann Bearings Corporation

...e Aeronautical Engineers Committee cold
...al test front and back external views.





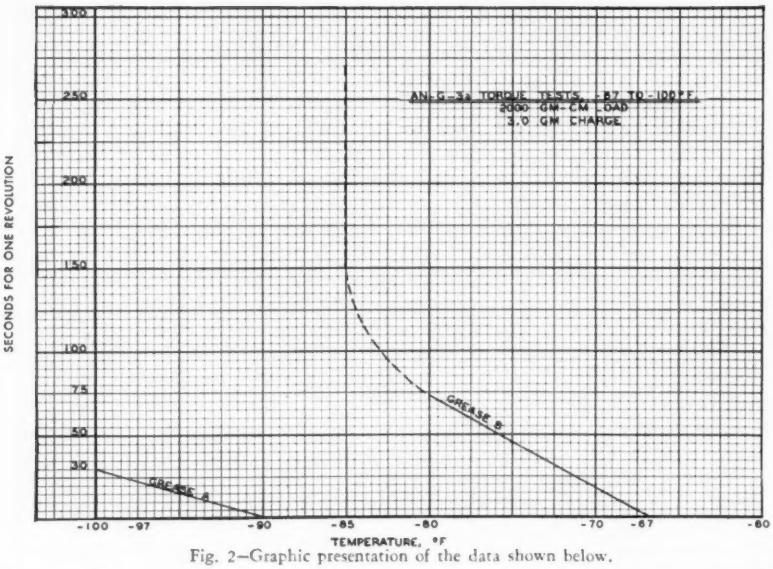


Fig. 2—Graphic presentation of the data shown below.

Torque Data

Figure 2 shows graphically the low temperature performance obtained when values for Grease A are plotted at various temperatures against those obtained for Grease B. It may be seen that the latter is on the borderline of unsatisfactory performance at −67°F., losing plasticity rapidly at −70°F. and freezing up completely at about −80°F. In contrast, Grease A shows a value of less than one second at −90°F. and is satisfactorily plastic at even −100°F.

The data expressed graphically in Figure 2 is presented in tabular form as follows:

AN-G-3a Torque Test 3.0 gram charge 2000 gm-cm. load	seconds for one revolution	
	Grease A	Grease B
−100°F.	24	stalled
−97°F.	19	stalled
−90°F.	less than 1	stalled
−80°F.	less than 1	73
−67°F.	less than 1	less than 1

The foregoing results demonstrate conclusively the superiority of Grease A at extremely low temperatures. Since "temperatures lower than −67°F. exist in the upper air at varying altitudes at all continental United States stations on practically all days" (according to the United States Weather Bureau) it seems definitely proven that the atmospheric temperature does not level off at high altitudes as has often been presumed. The corrolary to this fact is that a completely successful low temperature grease for modern military aircraft must operate successfully at the minimum temperature to meet all conditions encountered. In this connection Army Air Force personnel have given—90° F. as a condition to be met in future flight operations.[2]

A commercially available lubricant with satisfactory plasticity down to −100°F., thus extends the temperature range at which aircraft can fly continuously and also gives greater margins of successful performance at temperatures of −40 to −70°F. This latter achievement is very important in combating the cumulative stiffening effect on lubricants of Arctic ground temperatures after soaking periods of two or three days. Reports from these areas have indicated that aircraft controls may freeze up even while the plane is on the ground, thus making it difficult to take off quickly in times of emergency.

[2]Reference a paper on "Lubricating Grease Requirements for Modern Military Aircraft" by E. R. Irwin and Capt. S. C. Britton of the Army Air Forces, Materiel Command, Wright Field, Dayton, Ohio, presented at the Nov. 1943 meeting of the National Lubricating Grease Institute.

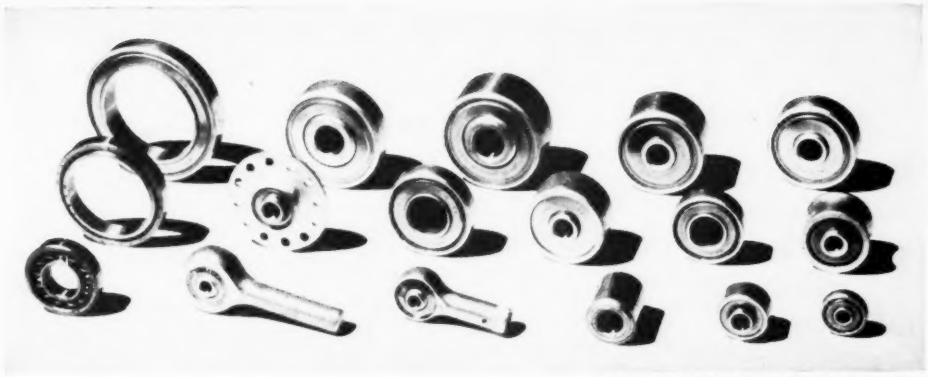
NATURE OF AIRCRAFT CONTROL MECHANISMS

The control mechanisms of an aircraft may be conveniently divided into two general types.

1. The ball bearing arrangements, which reduce friction at the points of rotation of control pulleys, bell cranks, rod ends, and the like.
2. The various types of small gears.

As Figure 3 indicates, the various types of ball bearings used in aircraft are tiny little gadgets, ranging from about 1.6 cm. diameter to around 12 cm. A No. 204 bearing is considered to be average size. The various control cables that branch off from the pilot's "stick" and rudder-pedals run over such pulleys to the control surfaces, such as the ailerons, elevators and rudder. Proper lubrication of these control bearings obviously is an important factor in obtaining quick and responsive action of the control surfaces.

Figure 4 shows a representative gear box mechanism with the top plate removed so that the various component gears may be seen. Such gear



Courtesy of The Fafnir Bearing Company

Fig. 3—An assembly of typical aircraft ball bearings.

boxes are widely used in aviation, usually being driven by a small high-speed motor. The gears act as a speed reducer to drive a screw feed arrangement which raises or lowers the landing flaps, motor cowl flaps, oil cooler flaps and other similar mechanisms.

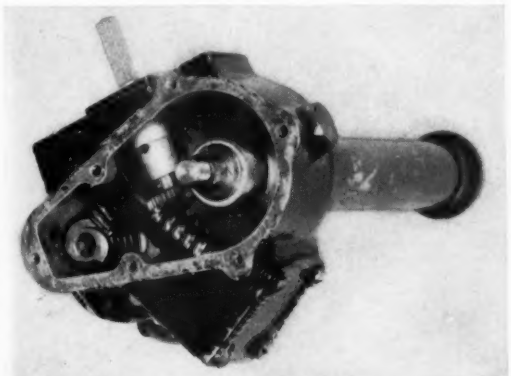
Rate of Motion

Aircraft control ball bearings work at slow speed usually oscillating in arcs of less than a complete revolution. Gear mechanisms, however, make complete turns at comparatively high speeds wherever motor speeds are to be reduced. In some of these mechanisms comparatively high tooth loading also will develop. Gear lubrication, therefore, must be studied from the viewpoint of channeling of the grease and scoring of the gears.

Grease Seal Important

Another very important requirement of an aircraft control bearing lubricant is that it protect the bearing parts against dirt and sand. For instance, in the case of an average small ball bearing the maximum seal clearance may be about 0.01 inches, whereas some sand found in the desert may be only 0.002 inches in diameter; thus the interior sealing effect of a suitable grease is definitely needed to keep fine sand particles from entering the bearing to cause serious wear of the precision parts.

Conditions of high humidity, such as exist in the tropics, and on sudden ascents and descents into different stratas of air at different temperatures and degrees of humidity, also indicate the need for a lubricant which will protect the bearing parts against moisture.



Courtesy of AirResearch Manufacturing Company

Fig. 4—A typical gear box mechanism.

WHAT LOW TEMPERATURE OPERATION MEANS

A grease to function effectually at very low temperatures must be able to

1 — Resist freezing or solidification.
2 — Seal bearings against dirt and moisture.
3 — Resist excessive channeling.
4 — Prevent gears from spalling.
5 — Shear readily.
6 — Lubricate dependably and
7 — Prevent corrosion or rusting.

Most aircraft control bearings and some of the smaller gears must operate with minimum drag at low temperatures for reasons which are obviously important. Thus they require a lubricant which will resist freezing, and shear easily at the lowest probable temperatures. If pulley control bearings and gears tighten up or freeze at the extreme low temperatures of the upper atmosphere, or under Arctic ground conditions, the pilot cannot maneuver his plane successfully. It is like trying to shift the gears of an automobile on a sub-zero morning when there has been no change to winterized lubricants; the congealed lubricant hangs onto the parts like chewing gum, requiring a feat of strength to secure any sort of operation.

In flight, where split second operation may be a matter of life and death, one can easily appreciate the morale-shattering effect on the pilot should his

trim-tab controls freeze up in a dive, or should the "stick" respond so sluggishly that he cannot escape the fire from an enemy plane. These same considerations apply to the motor-driven gear boxes which activate the landing flaps and important engine temperature control flaps. Here a frozen sticky grease around the gears will slow up the small, high speed motor so that the flaps do not function with the desired and necessary rapidity.

The most successful low temperature grease is the one which will feed readily to the parts to be lubricated without excessive channelling. Many of the small control bearings used on modern aircraft at times may carry heavy static loads, especially when the plane is pulling out of a dive. Lubrication of these bearings is most dependable when the grease resists channelling and follows the bearing elements with the least amount of drag or internal friction.

It is obvious that a low temperature grease must be easy to apply to the parts to be lubricated, which means that it should be of the proper consistency. An A.S.T.M. worked penetration range of 310-385 is considered suitable for aircraft control lubricants.

CONVERSELY – AT HIGHER TEMPERATURES

Not only must a low temperature grease function in extreme cold; it must also stay in the bearings at the highest temperatures which the planes encounter. The maximum high range for temperatures of the enclosed air spaces surrounding control bearings will range from 140-170°F. At these temperatures the grease must not bleed oil nor leak out of the bearing in any objectionable amount. A positive factor in producing leakage in aircraft ball bearings is the expansion due to entrained air when the plane ascends to higher altitudes. Leakage is particularly important in the case of factory-sealed ball bearings, some of which go into inaccessible plane locations where relubrication is difficult. In general, however, even a sealed bearing can be relubricated with the portable machines now on the market.

It is well known that increases in temperature accelerate chemical reactions such as oxidation, therefore the perfect low temperature grease should be well inhibited against oxidation and the formation of corrosive, oxidation end-products.

As successful low temperature greases contain mineral oils of low viscosity, evaporation of volatile constituents presents a problem in stability. To get away from arbitrary laboratory oven tests, one stage of the field research involved lubricating the control ball bearings in actual flying service over the California desert country. Later the bearings and grease used in these tests were subjected to laboratory study to determine the degree of wear, grease leakage, retention of low temperature properties, resistance to oxidation and general stability.

ACTION IN LONG TIME SERVICE

To function effectually for extended periods of time, the same grease must

Resist oxidation
Resist corrosion to copper or steel
Be as free as possible from foreign matter
Be moisture-resistant

The difficult conditions surrounding the proper lubrication of aircraft controls include as another factor the long-time stability of the grease at ordinary atmospheric temperatures, particularly in inaccessible bearings. Oxidation and/or corrosion reactions may take a different course at ordinary temperatures than at high temperatures, and a successful grease must be resistant to both types of changes.

In dealing with precision mechanisms such as modern ball bearings, lubricants of the best obtainable cleanliness must be used. Army-Navy Specification AN-G-3a for Low Temperature Grease, requires a microscopic dirt count, which insures that greases satisfactorily free from foreign matter are used in this connection.

A successful low temperature grease must also possess protective adherence. This is a measure of the sealing ability. Conditions of high humidity such as exist in the tropics and on sudden ascents and descents into stratas of air at different temperatures and degrees of humidity, indicate the need for a lubricant which will protect the bearing parts against moisture.

FIELD TESTS

The final test of the suitability of a low temperature grease quite naturally involves actual service in flight. Interesting test data is continually being accumulated on such vital aircraft mechanisms as

(a). The control surface mechanisms for the ailerons, elevators and rudder, and
(b). The trim tab mechanisms

These mechanisms include the whole system, from the pilot's cockpit control to the control surface in question; including the lubrication of cable pulley ball-bearings, flexible cables and certain gear systems. Flight tests of this nature produce much valuable data pertinent to the various materials that go into aircraft construction and operation. These basic facts which can be obtained in no other way should be the foundation of all material specifications.

Some idea of the extensive scope of Army Air Force testing of Aircraft greases can be ascertained from the recent article by Wright Field personnel on "Lubricating Grease Requirements for Modern Military Aircraft" previously quoted.

AN AVIATION GREASE . . . LOW-TEMP THAT WORKS AT . . .

MINUS 100° F

Based on the belief that the lowest stratosphere temperature was minus 67° F., Aviation greases were developed to lubricate at or above this temperature.

However, recent test flights recorded stratosphere temperatures ranging between minus 80° F. and minus 90° F. . . . other tests registered still lower temperatures. The U. S. Weather Bureau confirmed that temperatures lower than minus 67° F. exist in the upper air at all U. S. stations on practically all days.

On these test flights, greases made for minus 67° F. froze up. To correct this, Texaco developed a product which will permit all parts of the plane, where it is used, to function perfectly even at minus 100° F. . . . *Texaco* **LOW-TEMP.**

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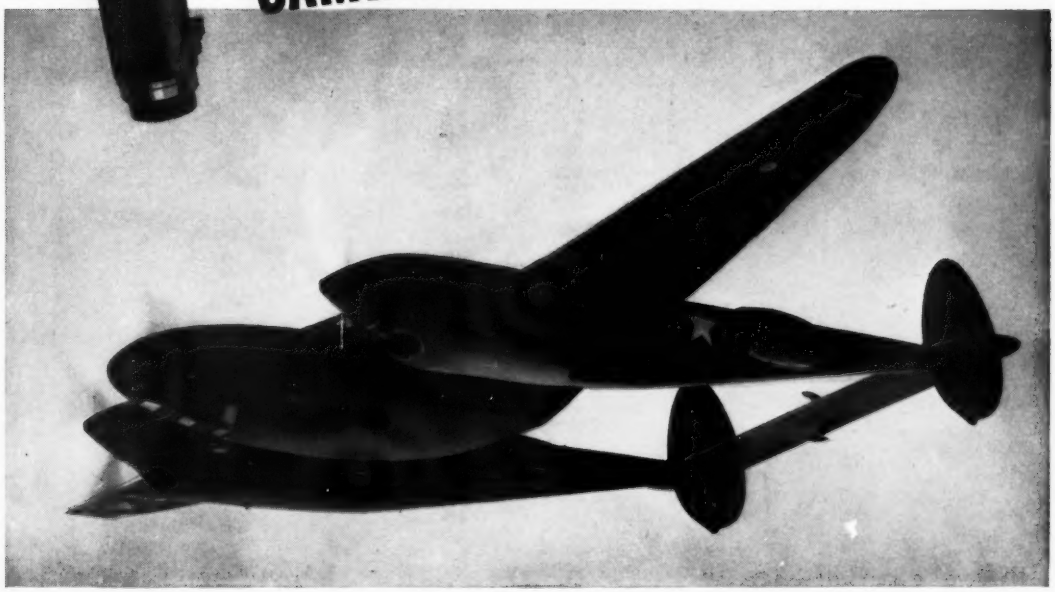
CAMERAS WORKING PERFECTLY



FLIGHT records show that planes flying at 30,000 ft. and above experience temperatures as low as minus 100° F. In this extreme cold, cameras and control mechanisms may freeze up, fail to function.

To correct this high-altitude flying hazard, we offer *Texaco* **LOW-TEMP** *Grease.*

Texaco **LOW-TEMP** *Grease,* the result of a 2 years' research, has had an enthusiastic reception because it assures efficient lubrication in temperatures as low as minus 100° F.

Throughout the industry —

More revenue airline miles in the U. S. are flown with Texaco than with any other brand.

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